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NASA GRC's High Pressure Burner Rig Facility and Materials Test Capabilities

R. Craig Robinson
Dynacs Engineering Company, Inc., Cleveland, Ohio

December 1999

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NASA GRC's High Pressure Burner Rig Facility and Materials Test Capabilities

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SUMMARY

The High Pressure Burner Rig (HPBR) at NASA Glenn Research Center is a high-velocity, pressurized combustion test rig used for high-temperature environmental durability studies of advanced materials and components. The facility burns jet fuel and air in controlled ratios, simulating combustion gas chemistries and temperatures that are realistic to those in gas turbine engines. In addition, the test section is capable of simulating the pressures and gas velocities representative of today's aircraft.

The HPBR provides a relatively inexpensive, yet sophisticated means for researchers to study the high-temperature oxidation of advanced materials. The facility has the unique capability of operating under both fuel-lean and fuel-rich gas mixtures, using a fume incinerator to eliminate any harmful byproduct emissions (CO, H₂S) of rich-burn operation. Test samples are easily accessible for ongoing inspection and documentation of weight change, thickness, cracking, and other metrics. Temperature measurement is available in the form of both thermocouples and optical pyrometry, and the facility is equipped with quartz windows for observation and video taping.

Operating conditions include:

- 1.0 kg/sec (2.0 lbm/sec) combustion and secondary cooling airflow capability.
- Equivalence ratios of 0.5–1.0 (lean) to 1.5–2.0 (rich), with typically 10 percent H₂O vapor pressure.
- Gas temperatures ranging 700–1650 °C (1300–3000 °F).
- Test pressures ranging 4–12 atmospheres.
- Gas flow velocities ranging 10–30 m/s (50–100) ft/sec.
- Cyclic and steady-state exposure capabilities.

The facility has historically been used to test coupon-size materials, including metals and ceramics. However, complex-shaped components have also been tested including cylinders, airfoils, and film-cooled end walls. The facility has also been used to develop thin-film temperature measurement sensors.

INTRODUCTION

The Environmental Durability Branch of the Materials Division has a mission to bring research materials to a higher level of technology readiness for advanced propulsion and power systems. Understanding the high temperature degradation mechanisms in advanced materials is fundamentally important in developing strategies to enhance and predict component durability in gas turbine engines. To accomplish this, burner rigs are a very valuable tool for simulating the harsh environments to which these materials will be exposed.

This report documents the unique capabilities of a high-pressure, high-temperature burner rig used and operated by the Environmental Durability Branch. HPBR test data has enabled researchers to make major contributions in our knowledge of advanced materials, such as silicon-based monolithic and composite ceramics durability. Important issues such as the effects of water vapor and scale volatility have been studied providing vital mechanistic and performance information. In addition, outside collaborations with government and industry have provided insight into the development of innovative component concepts and advanced sensor technologies.

TEST FACILITY DESCRIPTION

A schematic of the HPBR is shown in Figure 1. From right to left, combustion air, provided by a dedicated 400 hp compressor, enters the combustor and flows over the outside of the liner to provide cooling and to be preheated for more efficient combustion. The air is directed through a swirler in the combustor's dome, mixed with jet fuel supplied by an air-blast fuel nozzle, and ignited using a

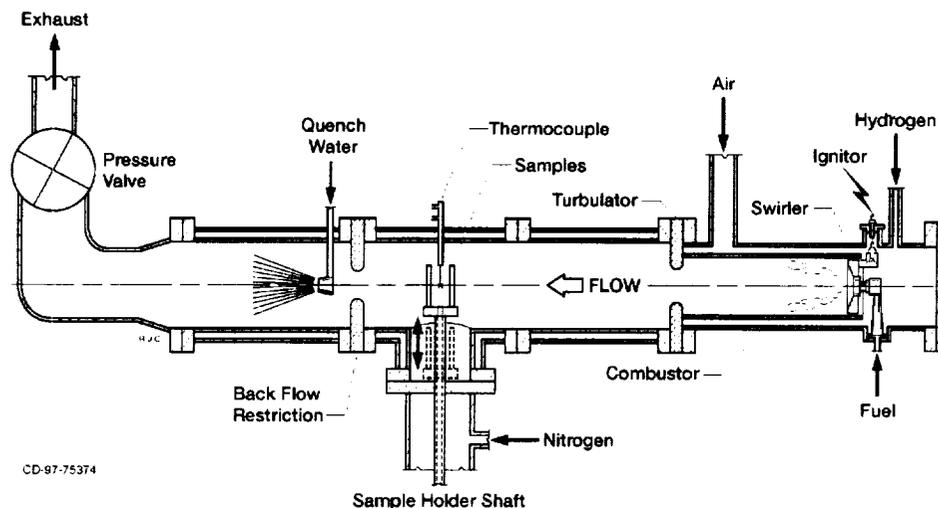


Figure 1.—Schematic of the High Pressure Burner Rig (HPBR).

spark plug and hydrogen. The combustion products flow downstream through a water-cooled turbulator orifice and optional transition section(s) as combustion is completed, incurring some heat loss before passing into the test section. Use of the transition section(s) will be detailed in later discussions.

The combustion gas flows downstream into the test section and over the specimen(s) held within a fixture. This specimen holder is mounted on a shaft that is accessible to the gas path through a "T-section", best illustrated in Figure 2. The mass flow, gas chemistry, velocity, and pressure are controlled in the test section, and temperatures are measured both optically and using thermocouple technology. The combustion gases are then quenched downstream by a water spray before passing through an exit valve that maintains system pressure. A second orifice, located between the test chamber and quench section, is used to create a pressure drop to prevent quench water from coming upstream.

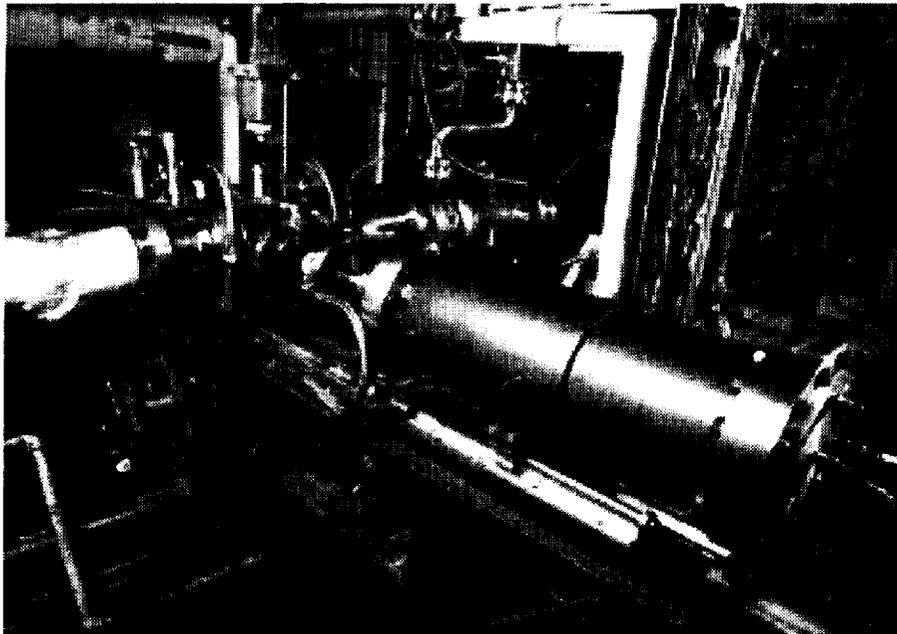


Figure 2 .—Photograph of HPBR featuring modular design.

Upon exiting the rig, the combustion products, condensed water, and steam pass through a particle separator and natural gas stack burner before being vented to the atmosphere. This is to remove water, soot, and by-product emissions (CO, H₂S) that are not environmentally acceptable. The HPBR is of modular design, and each section is easily accessible for assembly and maintenance operations. A more detailed description of the HPBR's primary modules follows, providing insight into understanding the design, capabilities, and operation of the facility.

Combustor

Shown in Figure 3, the combustor consists mainly of a housing, fin-cooled liner, swirler, and fuel injector. At the inlet, a manifold system distributes the airflow uniformly onto the liner and creates a pressure seal as the liner flange is pushed against the turbulator. The air passes through the annulus between the housing and outside diameter of the liner, entering the combustor dome through the swirl plate and air-blast fuel nozzle. The swirl plate and nozzle are secured (pinned) in the housing, lending to a “free-floating” metal liner that is completely unconstrained to expand and contract during operation. For this, the liner is slotted to allow for growth over the swirler and past the pins. This eliminates severe buckling encountered in earlier designs with less freedom. The combustor liner also utilizes a plasma-sprayed thermal barrier coating (TBC) to improve durability.

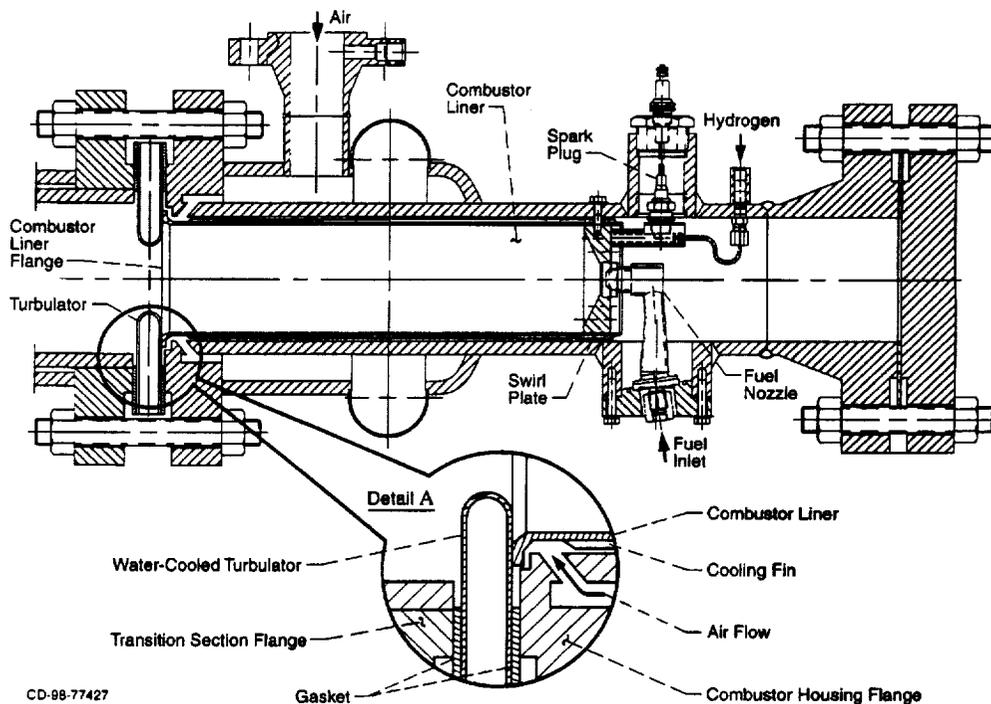


Figure 3.—Schematic of HPBR combustor.

The current configuration includes numerous modifications to earlier designs to improve fuel-to-air mixing and optimize liner durability. Today's current configuration is known for state-of-the-art fuel mixing and component durability measured in thousands of hours. The swirler and air-blast fuel nozzle of this design have greatly improved temperature profiles, flame stability, and soot resistance as compared to that of original designs. This development has been detailed in previous publications [1-2].

Test Section

The test section is a 6 inch diameter "T-shaped" chamber through which the combustion gases flow, while being directed over the specimen holder and test specimen(s) inserted at an angle normal to the flow. Figure 4 shows the test section featuring an observation window, shown at the top of the section, which is used as a viewport for optical temperature measurement. The quartz window is washed with cool nitrogen to prevent cracking and soot deposition, while the test section, sample holder, and adjacent transition section are each fully water-cooled and sprayed with a TBC coating for improved durability. The "T-section" provides access for the specimen holder and can accommodate specimen geometries (including holder) of approximately 10 cm. (4 in.) diameter x 15 cm (6 in.) when inserted.

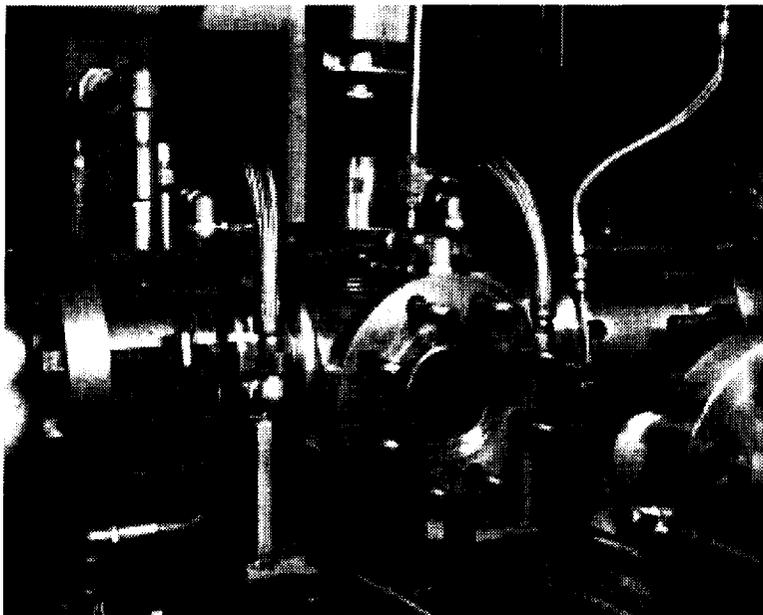


Figure 4.—Test section with viewport, pyrometer, and test specimen access flange.

The standard specimen configuration, shown in Figure 5, is used for coupon testing of candidate materials. The test samples, arranged in a wedge configuration, are loosely contained in slotted superalloy grips within the holder. Sample width and thickness may vary slightly, but a standard sample size (7.6cm x 1.3cm x 0.3cm) is preferred, accommodating a total of 4 samples in the 1.3cm (.5 in) configuration (Figure 5a). A thermocouple probe measures the gas temperature at a position centered 2–3 cm behind the wedge, and optical pyrometry is available through the viewport for measuring sample temperatures. As shown in Figure 5b, thin-film and thin-wire thermocouples have also been used for recording specimen temperatures.

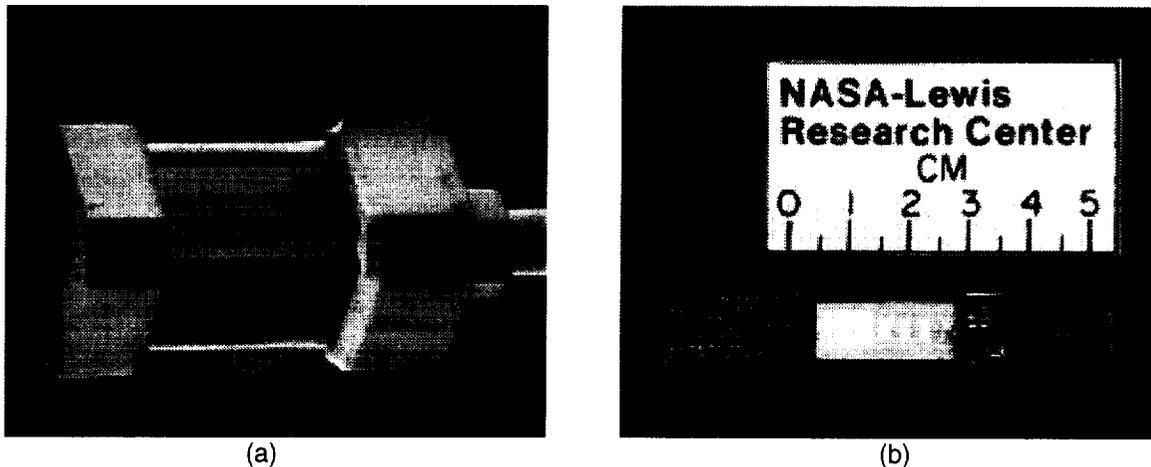


Figure 5.—HPBR (a) specimen holder and (b) standard test specimen with thermocouple instrumentation.

Support Systems

There are a number of other component sections and systems critical to the operation of the HPBR. As mentioned, a dedicated 400 hp compressor is used to supply the high volume of air required to operate the facility. Downstream of the test area, a water-quench section and liquid/gas separator are used to cool the affluent and remove any condensate. A natural gas fume incinerator burns off any environmentally hazardous emissions, typically carbon monoxide. In addition, the facility has a fully automated data acquisition and control system. This is critical in maintaining a reliable and well-documented test. These support systems are also described in the previous reports [1-2].

TESTING

Operating Specifications

To simulate gas turbine conditions for materials test purposes, the primary variables of interest are temperature, pressure, gas flow velocity, and most importantly, the gas composition. Table 1 summarizes the operating envelope of the HPBR for both lean and rich-burn operation. The standard test is to control the equivalence (fuel-to-air) ratio, ϕ , at a fixed test pressure (6 atm) and mass airflow (1.0 lbm/sec). This airflow and pressure is recommended to provide adequate cooling and optimal durability to the combustor liner over the entire operating range, however lower airflows are possible for moderate combustion temperatures. The resultant temperatures and gas velocity are thus dependant variables fixed by the airflow, fuel-to-air ratio, and pressure. Velocity is calculated from the ideal gas law, given the area at the test section. Once at the desired test conditions, the specimens are pneumatically inserted into the gas stream.

Table 1.—Summary of HPBR experimental test envelope.

	Lean-Burn	Rich-Burn
Air Flow	0.45–0.70 kg/sec	0.45–0.6 kg/sec
Equivalence Ratio	0.35–1.0	1.0–2.0
Pressure	4–15 atm	4–15 atm
Gas Velocity	10–30 m/s	10–30 m/s
Gas Temperature	1000–1550 °C	1350–1550 °C
Sample Temperature*	800–1400 °C	1250–1475 °C

* SiC reference, other materials vary.

Test conditions are variable depending on requirements, however there are limitations for varying parameters independently. Operation at slightly higher airflow is possible for lean-burn conditions, however the CO fume incinerator is limited to approximately 0.6 kg/sec under rich-burn conditions. Regarding fuel flow, the region around stoichiometry ($\phi=1.0-1.5$) is avoided due to the high temperatures associated with this region, while equivalence ratios in excess of 2.0 are avoided because of sooting. Minimum pressure (4–5 atm) is driven by the minimum airflow mentioned, as well as the maximum exit area. Maximum pressure (10–15 atm) is limited by the requirement to maintain a sufficient pressure drop across the swirler for proper fuel-to-air mixing, which may necessitate an increase in the mass flow. Accordingly, an increase in pressure will decrease the velocity, while an increase in mass flow will produce a proportional increase to the velocity.

Materials Temperatures

Due to the specimen holder's wedge appearance (Figure 5a), the two inside samples generally run hotter than the outside samples as a result of significant axial and radial temperature differences. These inside samples are referred to as leading edge (LE) samples, while the outside samples are referred to as trailing edge (TE) samples. Figure 6 shows gas and sample temperatures obtained as a function of the fuel-to-air ratio¹ for a typical SiC run. As expected, the maximum temperatures are observed near stoichiometry and avoided for rig durability reasons. The axial and radial temperature gradients create a typical temperature drop of 25–50 °C between the LE and TE samples. The magnitude of this temperature difference depends on pressure and velocity. As mentioned, the water-cooled transition section(s) are optional, enabling direct tradeoffs between gas chemistry and temperature by utilizing the heat losses. As a result, f/a-temperature curves are typically calibrated for each configuration, as well as material.

¹Equivalence ratio (ϕ) is the fuel-to-air ratio (f/a) normalized to hydrocarbon and oxygen content. For jet fuel $f/a=\phi \times 0.068$ where stoichiometry ($\phi=1.0$) results in complete combustion.

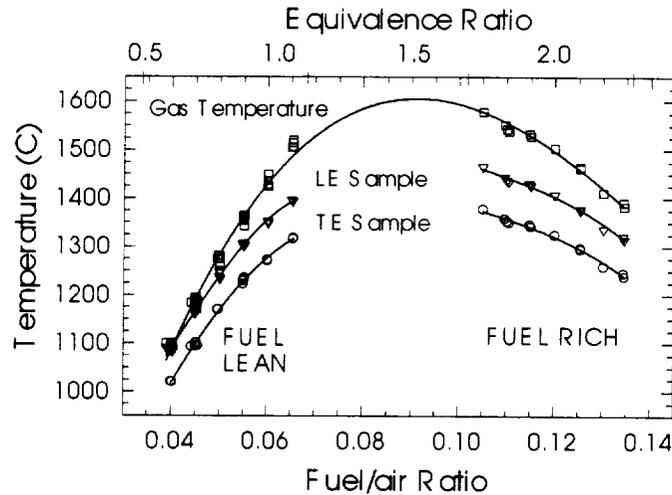


Figure 6.—Typical gas and sample temperatures as a function of f/a ratio for CVD SiC.

To generate f/a curves such as Figure 6, a water-cooled thermocouple probe is used to measure the combustion gas temperature, while specimen temperatures are generally measured using pyrometry. This technique works well under lean-burn conditions, and the accuracy of the pyrometer readings has been verified through alternative temperature measurement using instrumented specimens. In Figure 7, sensors on both LE and TE samples measured temperatures as expected (from pyrometry) relative to their position as well as the combustion gas temperatures, as suggested by the f/a curves.

Under rich-burn conditions, the samples are not visible due to the intense luminosity of the flame, and sample temperatures cannot be measured directly using pyrometry. Instead, sample temperatures are calculated using the correlation between pyrometer and combustion gas temperatures measured in lean-burn operation. The correlation, a least squares straight line regression, is very repeatable and can be input into the computer and used for "real-time" temperature estimation during the test.

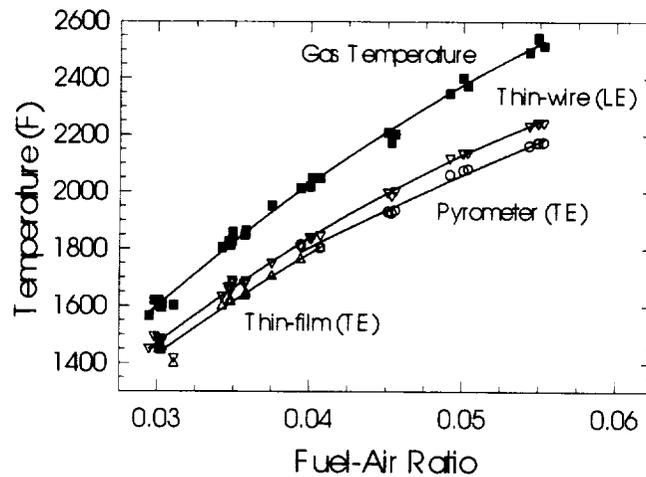


Figure 7.—Temperatures measured using thin sensors agree with thermocouple (gas) and pyrometer (sample) readings.

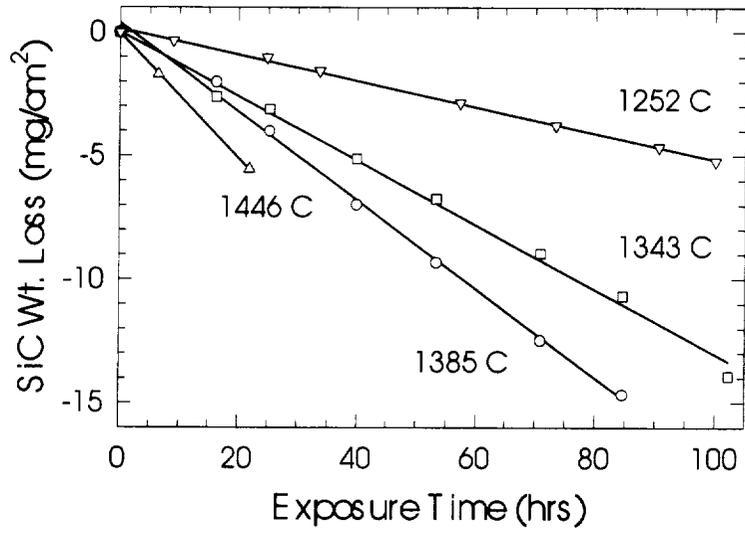
Oxidation Studies

At this point, it is helpful to point out the benefits and potential uses of such a unique facility as the HPBR. Generally speaking, burner rigs offer certain advantages over furnace testing and other methods in materials evaluation for high temperature engine applications. Complex issues such as thermal stresses, moisture, and oxidizing atmospheres are more realistically simulated in the harsh environment combustion rigs such as the HPBR can provide. Lean operation produces combustion products consisting of 10%O₂–8%H₂O–7%CO₂–bal. N₂ ($\phi=0.5$), while rich operation results in a combustion chemistry of 6%H₂–12%H₂O–12%CO–5%CO₂–bal. N₂ ($\phi=1.5$) [3]. From thermal shock to long-term exposure, the HPBR has a wide range of capabilities to conduct various types of studies, however oxidation studies have been the main focus of testing.

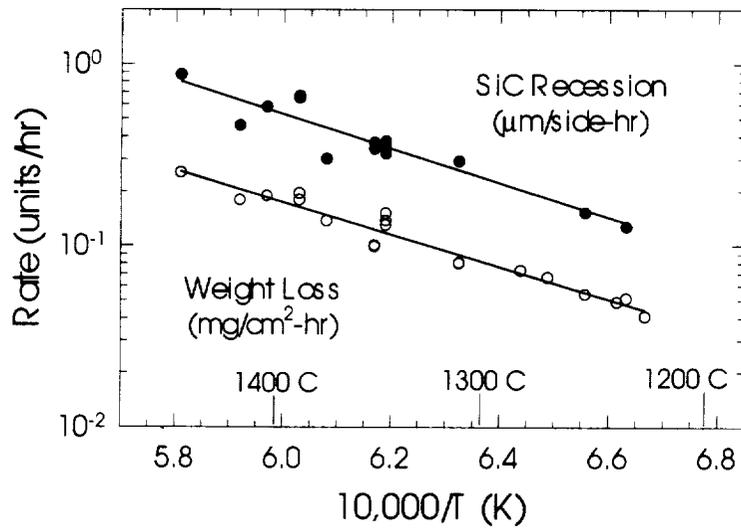
As mentioned, the HPBR has been instrumental in making significant contributions into the understanding of high-temperature oxidation of Si-based materials, namely SiC. Specifically, environmental durability studies benefit from the high pressure, water-laden atmospheres present in facilities such as the HPBR. In fact, during initialization of NASA's government-industry partnership, the Enabling Propulsion Materials (EPM) Program, NASA and leading engine makers were eager to identify a primary vehicle for hot gas testing. After an extended search, the team recognized the HPBR as unique among existing facilities with respect to gas chemistry, operating regime, and user friendliness. As a result, the facility was adopted as one of the EPM programs' primary materials development test facilities.

As an example, recession of SiC materials was identified as a primary concern in both fuel-lean and fuel-rich environments [4]. To augment the analytical and furnace data, an extensive series of tests was performed in both gas mixtures to determine the recession rates of SiC due to SiO₂ scale volatility in the presence of water vapor. Figure 8 shows select results from the rich-burn study conducted at 6 atm, 25 m/s, and 1200–1400 C. In Figure 8a, SiC weight loss is plotted versus time at various temperatures. Both linear rate losses and a strong temperature dependence are evident. Figure 8b shows these and other rates, along with those obtained from direct thickness measurements in an Arrhenius-type form with the two rates agreeing as expected from density calculations. This type of data was critical in developing the life prediction models for these materials.

As stated, coupon testing is the primary focus of the HPBR, specifically concerning high temperature oxidation behavior in the presence of water vapor. In addition to SiC materials, efforts have been directed towards metals, Si₃N₄ materials, and numerous coating systems. However, some exciting programs have demonstrated alternate configurations such as airfoil or combustor applications. A few examples are discussed below.



(a)



(b)

Figure 8.—Recession of CVD SiC under rich-burn as (a) weight loss vs. time and (b) an Arrhenius dependence for weight loss and thickness measurements [4].

ALTERNATE CONFIGURATIONS

In addition to standard coupon testing, the HPBR can accommodate component testing for aeronautic programs that feature requirements such as complex geometry, transpiration cooling, or even flight cycle simulation. A number of successful studies have been completed in the facility, each requiring specific modifications to rig hardware and software to accomplish the desired goals. In each case, the HPBR's versatility enabled effective solutions to be developed and implemented in a timely manner. Some examples are given below.

As part of a turbine airfoil program, a series of fiber-reinforced ceramic matrix composite (CMC) airfoils were exposed in the HPBR under simulated gas turbine conditions. Shown in figure 9, the SiC/SiC CMC airfoils featured transpiration cooling air holes and a complex geometry including a twist. Here, alternate specimen holders were fabricated to secure the airfoils and deliver the required cooling to the internal blades. The cooling air can also be preheated and is capable of being delivered at pressures as high as the external pressures.

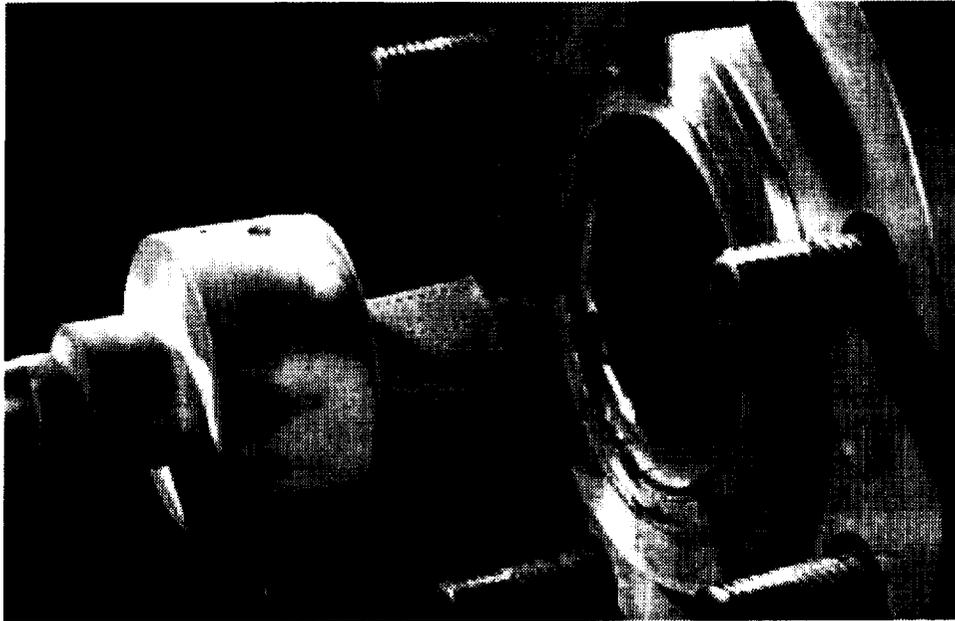


Figure 9.—Transpiration-cooled SiC/SiC airfoil prototype.

In a second example, a concept for a combustor liner application was creatively installed and evaluated within another useful test area of the HPBR. A large CMC cylinder was mounted in a modified transition section designed to place the cylinder in the open area between the combustor and test sections. As shown in Figure 10a, the 4" OD x 8" C/SiC tube was suspended on six (6) water-cooled legs used to support the structure and accommodate thermocouple probes. After 50 hrs of exposure at material temperatures near 2500 °F, the cylinder (Figure 10b) shows some cracking and slight oxidation. Also visible in

Figure 10, three (3) thin-film sensors applied by NASA GRC's research engineers (Sensors and Electronics Technology Branch) were used to monitor materials temperatures while the remaining three (3) probes monitored the gas temperatures.

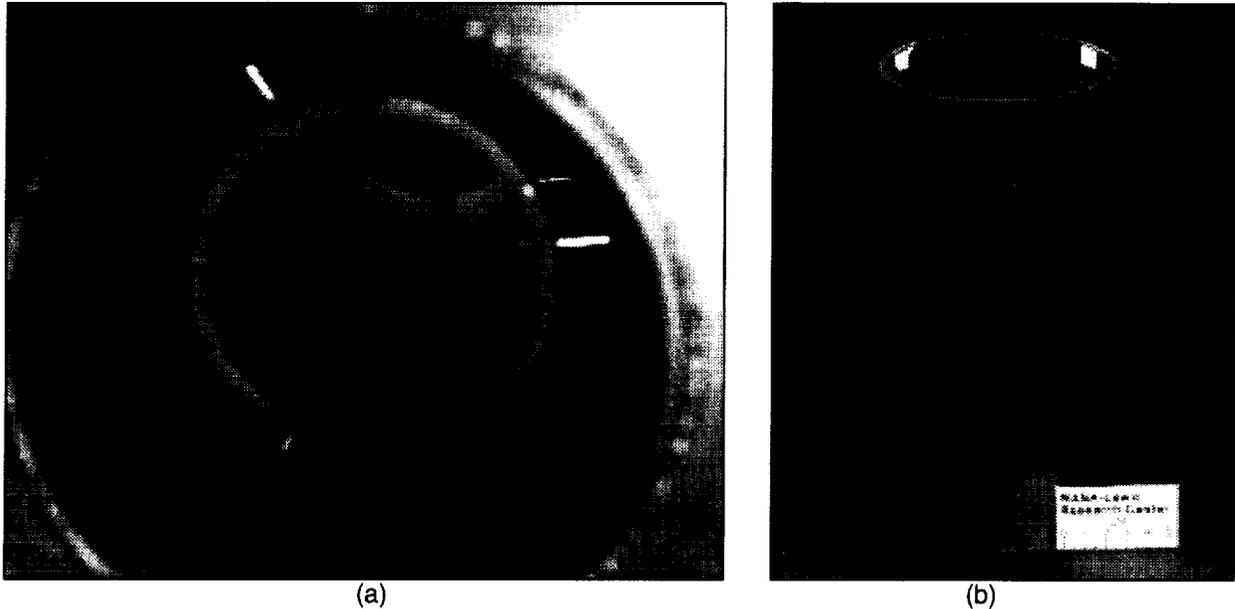
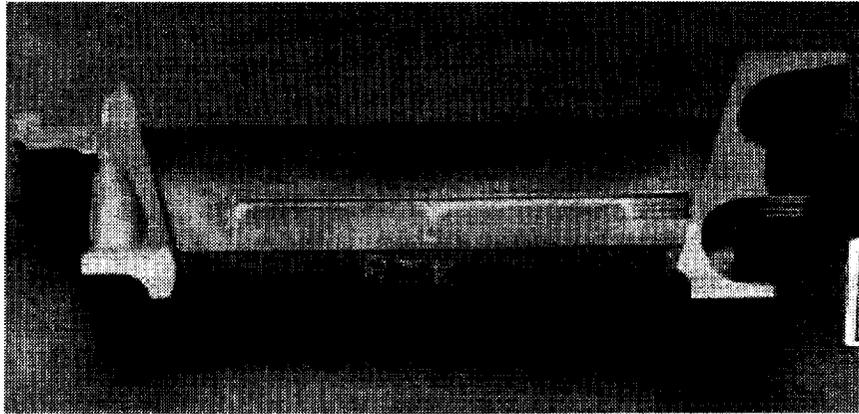
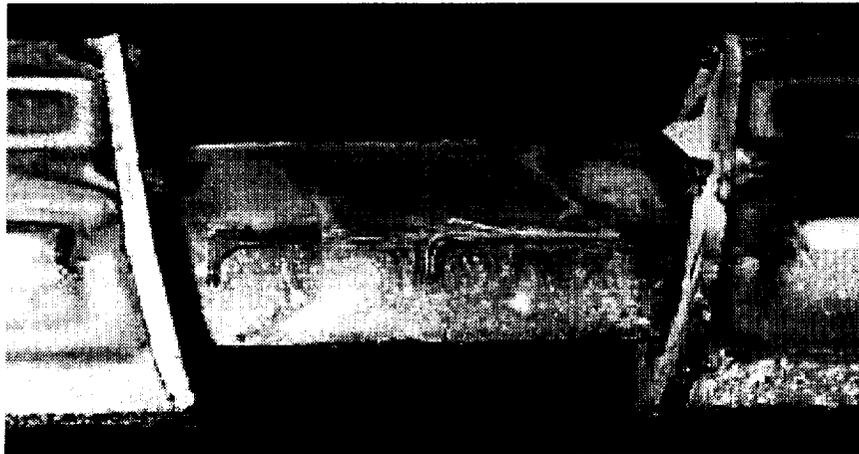


Figure 10.—CMC cylinder (a) installed within HPBR transition and (b) shown after test with apparent cracking and oxidation.

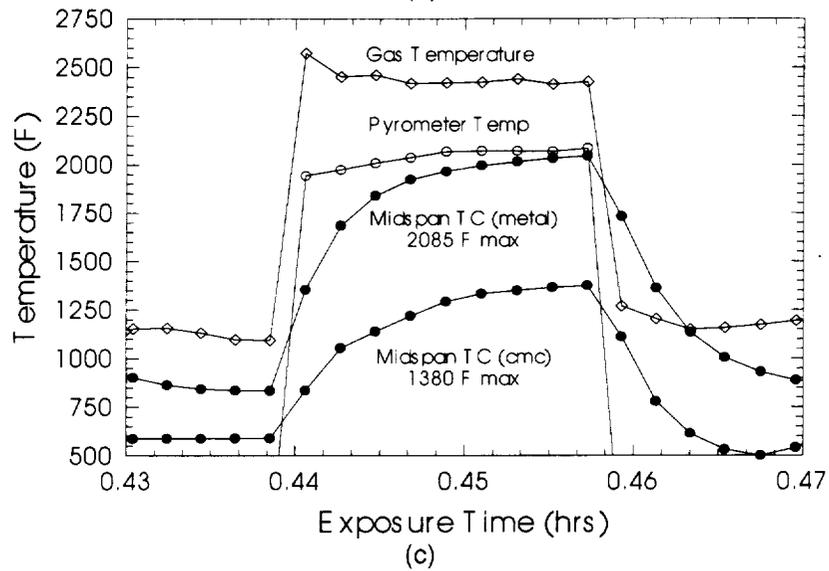
As a final example, the HPBR was used to cycle an innovative SiC/SiC leading edge airfoil between simulated idle, lift, and cruise flight conditions to determine the concepts' durability and temperature benefits [5]. The 2nd stage high pressure turbine vane of the Pegasus F402-RR-406 engine, powerplant of the Navy's Harrier fighter, was equipped with an AlliedSignal Composites, Inc. ceramic matrix composite (CMC) insert as shown in Figure 11a. The CMC airfoil, along with a metal baseline vane (Figure 11b), was air-cooled, uniquely instrumented, and exposed to flight cycles intended to simulate the Harrier mission cycle. Testing successfully reproduced failures on the metal vane similar to those seen in service, while demonstrating the durability of the SiC/SiC insert and reduced leading edge temperatures, as shown in Figure 11c. Although not shown, the cycle also included step changes in external gas pressure and velocity, further demonstrating the extended capabilities of the facility.



(a)



(b)



(c)

Figure 11.—Airfoil testing including (a) SiC/SiC leading edge (b) metal baseline failures (instrumentation visible) and (c) simulated cyclic exposure with documented temperature relief [5].

CLOSING REMARKS

The High Pressure Burner Rig (HPBR) test facility at NASA GRC is a relatively inexpensive, versatile system for providing researchers within the aerospace community with valuable information on the durability of advanced, high temperature materials and component concepts. The rig burns jet fuel and air in controlled flows to simulate temperature, pressure, and velocity representative of gas turbine conditions. Extensive redesign, modification, and evolution of the original combustor has optimized fuel-air mixing and made possible both lean-burn and rich-burn capabilities. In addition, improved component durability and a wide range of operating capabilities have earned the HPBR a long-standing reputation for reliability and longevity. High temperature and pressure, modest velocity, and a water-laden atmosphere are among the HPBR's primary attributes, but ease of operation and alternate configurations are two other very important intangibles to be considered. All this, along with the typical advantages provided by burner rigs over other test methods, has made the HPBR a unique, state-of-the-art combustion facility.

REFERENCES

1. C.A. Stearns and R.C. Robinson, "NASA Lewis Research Center Lean-, Rich-Burn Materials Test Burner Rig," NASA CR-194437, February 1994.
2. R.C. Robinson, "SiC Recession Due to SiO₂ Scale Volatility Under Combustor Conditions," NASA CR-202331, March 1997.
3. N.S. Jacobson, "High Temperature Durability Considerations for HSCT Combustor, NASA Tech. Paper 3162, January 1992.
4. R.C. Robinson and J.S. Smialek, "SiC Recession Caused by Scale Volatility under Combustion Conditions: Part I, Experimental Results and Empirical Model," J. Am. Ceram. Soc., 82 [7], 1817-1825, 1999.
5. R.C. Robinson and K.S. Hatton, "SiC/SiC Leading Edge Turbine Airfoil Tested Under Simulated Gas Turbine Conditions, NASA CR-209314, September 1999.

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